High Voltage Lateral 4H-SiC JFETs on a Semi-insulating Substrate

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Outline

- Introduction
- Concept and Design
- Fabrication Process
- Results
- Summary
Introduction

- 4H-SiC power devices have shown promising performance due to superior material properties ($E_g = 3.24$ eV, $E_c = 2-4E6$ V/cm, $k = 4.9$ W/cmK).

- Lateral devices have the advantage of being integrated with other devices.

- 4H-SiC lateral devices have broken through the limit of Si vertical devices.
  - $1000$ V, 9.2 m$\Omega$-cm$^2$ 4H-SiC lateral JFET
  - $1380$ V, 66 m$\Omega$-cm$^2$ 4H-SiC lateral MOSFET
Conventional vs. Proposed Approach

- REduced SURface Field
- Breakdown in the bulk
- Thick and lightly doped p-layer

- Semi-insulating substrate
- Charge compensation of n- and p-type epi-layers
Effects of Field Plates on Proposed Structure

- Field plates reduce electric field crowding at the junction corners.

- BV = 1280 V Without FP
- BV = 5200 V With FP

Junction depth = 0.5 μm
Ld = 80 μm

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High Voltage Lateral SiC Diodes

- BV = 3130 V has been demonstrated on a Ld = 80 μm lateral diode.

4H-SiC Lateral JFET Design

- \( Q_n = 7 \times 10^{12} \text{ cm}^{-2} < Q_c = 1.1 \times 10^{13} \text{ cm}^{-2} \)
- \( Q_p = 6 \times 10^{12} \text{ cm}^{-2} < Q_c \)
- \( L_d = 25, 50, 80, 100 \mu\text{m} \)
- \( L_g = 9, 15 \mu\text{m} \)
Fabrication of 4H-SiC Lateral JFETs (1)

- 0.12 μm RIE for P+ sinker
- Aluminum implantation at 650 °C for P+ gate and P+ sinker
- Nitrogen implantation at room temperature for source and drain
- Implant activation at 1650 °C for 30 min in Ar
Fabrication of 4H-SiC Lateral JFETs (2)

- RIE 1.9 μm in SF$_6$/O$_2$ to form isolation trenches
- Thermal oxidation at 1180 °C for 6 hrs to passivate the surface
Fabrication of 4H-SiC Lateral JFETs (3)

- Lateral out-diffusion of Al was observed during high temperature anneal in a test run
- E-beam evaporate Ti/Ni as both n- and p-type contact metals
- Anneal both contacts at 1100 °C for 3 mins in vacuum

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Fabrication of 4H-SiC Lateral JFETs (4)

- Deposit 0.5 μm of PECVD oxide as field oxide
- Open windows
- E-beam evaporate 0.8 μm of Al/Ti as pads and field plates

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Forward and Reverse Characteristics

- $V_{gs} = -16.7 \text{ V}$
- $BV = 3510 \text{ V}$ and $R_{on,sp} = 390 \text{ m} \Omega \cdot \text{cm}^2$ were achieved on a $L_g = 9 \mu\text{m}$, $L_d = 100 \mu\text{m}$ device. ($L_{fpg} = 10 \mu\text{m}$, $L_{fpd} = 25 \mu\text{m}$)
- The active area is $0.0228 \text{ mm}^2$.
- $I_{on}/I_{off} > 1000$
Transfer Characteristics

- $I_g < 1\text{E-8 A}$ until gate junction turns on at $V_{gs} = 3 \text{ V}$.
- The pinch-off voltage is about $-11 \text{ V}$. Peak $g_m$ is $1.21 \text{ mS}$ at $V_{gs} = 2.5 \text{ V}$.

$V_{ds} = 25\text{V}$

$g_m = 1.21 \text{ mS}$
In a Lg = 9 μm, Ld = 100 μm device, R_{drift} is about 61% of R_{total} and R_{channel} is about 18.6%.
Temperature Characterization

- $R_{on,sp}$ increases with temperature following a $T^{2.2}$ relationship ($\mu_n \sim T^{-2.4}$ in 4H-SiC).

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Drain Current Drift

- Drain current drift is observed as in 4H-SiC MESFETs.
- The reduction of drain current is less than 8% at $V_{gs} = 0$ V.
The trapped electrons deplete the channel and the n-type layer.

The trapped electron density is less than 8\% of $Q_n$. Its effects on charge balance and BV are not clear at this point.
Comparison of 4H-SiC Lateral Devices

<table>
<thead>
<tr>
<th>L_d (μm)</th>
<th>BV (kV)</th>
<th>R_{on,sp} (mΩ-cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1.27</td>
<td>66</td>
</tr>
<tr>
<td>50</td>
<td>1.51</td>
<td>145</td>
</tr>
<tr>
<td>80</td>
<td>2.32</td>
<td>291</td>
</tr>
<tr>
<td>100</td>
<td>3.51</td>
<td>390</td>
</tr>
</tbody>
</table>

BV²/R_{on} = 32 MW/cm²
Summary

- High voltage SiC lateral JFETs are demonstrated on a semi-insulating substrate.

- $R_{\text{on,sp}} = 390 \text{ m}\Omega\cdot\text{cm}^2$, $BV = 3510 \text{ V}$ for a $L_g = 9 \mu\text{m}$, $L_d = 100 \mu\text{m}$ device.

- $R_{\text{drift}}$ contributes about 61% of $R_{\text{total}}$ in a $L_g = 9 \mu\text{m}$, $L_d = 100 \mu\text{m}$ device. $R_{\text{channel}}$ contributes about 18.6%.

- Drain current drift was observed and attributed to trapping effects.